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Original Contributions

PERFUSION INDEX MEASUREMENT IN PREDICTING HYPOVOLEMIC SHOCK IN TRAUMA PATIENTS

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☐ **Abstract—Background: Perfusion index (PI) derived from pulse oximeter shows the ratio of the pulsatile blood flow to the nonpulsatile blood flow or static blood in peripheral tissue. Objectives: The aim of this study was to investigate the relationship between PI and blood transfusion necessity in 24 h and stage of hemorrhagic shock, as well as the utility of PI according to laboratory and clinical parameters, and determining the major risk of hemorrhage. Methods: PI was measured with a pulse oximeter in 338 patients (235 males, average age 41.8 ± 17.94 years). Laboratory parameters (hemoglobin, hematocrit, lactate, base deficits, pH) and clinical parameters (pulse rate, respiratory rate, SpO_2, systolic blood pressure [SBP] and diastolic blood pressure [DBP]), shock index (SI) and revised trauma score (RTS) were recorded. Univariate analysis was used to determine major risk for bleeding, and the receiver operating characteristic curves were performed to compare parameters. Results: PI was < 1 in 39 (11.5%) patients. Positive correlation between PI and hemoglobin ($p < 0.001$; r: 0.320), hematocrit ($p < 0.001$; r: 0.294), base deficit ($p < 0.001$; r: 0.315), pH ($p < 0.05$; r: 0.235), SBP ($p < 0.001$; r: 0.146), DBP ($p < 0.001$; r: 0.259), SpO_2 ($p < 0.001$; r: 0.197), RTS ($p < 0.001$; r: 0.344), and negative correlation with lactate ($p < 0.05$; r: −0.117), pulse ($p < 0.001$; r: −0.326), respiratory rate ($p < 0.001$; r: −0.231), and SI ($p < 0.001$; r: −0.257) were detected. A difference was detected between class 1 and 2, and class 1 and 3 (both $p < 0.05$) in hemorrhagic shock. Thirty-one with PI < 1 had blood transfusion within 24 h ($p < 0.001$; odds ratio 111.98, sensitivity 75.6%, specificity 97.3, positive predictive value 79.5%, negative predictive value 96.7%). The main risk factors of the need for blood transfusions were PI, pulse rate, and SpO_2. PI was more significant than lactate, base deficit, RTS, and SI measurements. Conclusion: PI might be beneficial in the detection and exclusion of critical patients and blood transfusion needs in the emergency department. PI can be used with vital signs and shock parameters in the early diagnosis of hemorrhage.** **© 2020 Elsevier Inc. All rights reserved.**

☐ **Keywords—perfusion index; multitrauma; outcome; blood transfusion**

INTRODUCTION

In trauma patients, hemorrhage is the most common cause of shock and is one of the leading causes of mortality (1). If bleeding is detected at an early stage, it is one of the most preventable causes of death after injury (2). Fluid and blood resuscitation is an important step in the prevention of early complications due to bleeding in trauma patients.

As a result of hypovolemia caused by blood loss, vasoconstriction occurs in the cutaneous, muscle, and visceral

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circulation in the early period to compensate for blood flow to vital organs. Therefore, there is a risk of imbalance between energy supply and needs in nonvital organs that may cause tissue hypoxia and lactic acidosis that could contribute to microcirculatory dysfunction (3).

Consciousness, skin color, and vital signs measurements such as pulse rate, respiratory rate, and blood pressure, and laboratory tests such as hematocrit, hemoglobin, lactate, and base deficit (BD) give important information about the severity of trauma (4). Shock index (SI) on arrival can be considered as a clinical indicator of hypovolemic shock in terms of transfusion requirements (5). Revised trauma score (RTS) is known as the current standard physiologic scoring tool used in the trauma setting and has accuracy and precision in predicting mortality (6). Relying on systolic blood pressure and pulse rate as an indicator of shock can delay the recognition of the shock. Laboratory values for hematocrit or hemoglobin concentration may be unreliable for estimating acute blood loss and should not be used to exclude the presence of shock (4). Multiple studies have shown the usefulness of blood lactate and BD in trauma patients as markers of injury severity and as predictors of outcome (7–10). Studies show that BD also may be a predictor of shock, and lactate alone may indicate the severity of hypoperfusion, but not necessarily for the extent of underlying metabolic acidosis (11–13). Therefore, besides these commonly used parameters, new research is needed to show hypovolemic shock and the need for blood transfusion. Hence, perfusion index (PI), which is a measurement of peripheral tissue perfusion, may be one of these innovations.

PI derived from a pulse oximeter shows the ratio of the pulsatile blood flow to the nonpulsatile blood flow, or static blood, in peripheral tissue, and is an indirect and noninvasive measure of peripheral perfusion in a specific monitoring site (e.g., hand, finger, or foot). It is calculated by using pulse oximetry. The pulsatile signal (i.e., during arterial inflow) is expressed as a percentage of the nonpulsatile signal, both of which are derived from the amount of infrared (940 nm) light absorbed by the blood in a noninvasive finger sensor (14). Although the manufacturer reports lower and upper limits of normal as 0.3 (very weak pulse strength) and 20.0 (very strong pulse strength), respectively, the clinical application of this ratio as peripheral PI has not been studied in trauma patients.

The aim of this study was to investigate the correlation of PI values with vital signs, laboratory and clinical parameters, and blood transfusion necessity in 24 h in multitrauma patients in the emergency department (ED).

MATERIALS AND METHODS

This retrospective study was conducted in the ED of a University Hospital between December 1, 2017 and September 5, 2018. There were 338 multitrauma patients included in the study. The study was conducted in accordance with the revised Declaration of Helsinki and was approved by the Research Ethics and Review Board of the University Medical Center.

This study included multitrauma patients who were 18 years old and older and admitted to the ED. Exclusion criteria included: age < 18 years, pregnancy, intubation prior to PI measurements, and patients with known diseases such as right ventricular failure, right ventricular hypertension, tricuspid valve disease, pericardial pathologies, anticoagulant medication, and peripheral artery disease, and known bleeding disorder because peripheral circulation may be impaired. Also, patients with any extremity fractures that could affect PI measurement due to impaired circulation were excluded from the study.

Data Source and Collection

Demographic features of the patients (age, gender), comorbidities, trauma mechanisms, vital signs such as systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse rate, respiratory rate, oxygen saturation (SpO_2), SI, laboratory tests (hemoglobin, hematocrit, pH, lactate, BD), RTS, and class of shock obtained at the time of ED admission were all evaluated from the patient's records; blood transfusion within 24 h was also recorded. None of the patients was prescribed additional medications such as vasopressors or blood products other than saline prior to the hospital.

All PI measurements of multitrauma patients were performed within the first 5 min of admission to the ED, in a resuscitation room at constant temperature (24°C). For PI measurements, a photoelectric plethysmographic signal of the pulse oximeter (Masimo SET Radical-7, Masimo Corp., Irvine, CA) was used. A reusable sensor was attached to the patient's right/left finger (Masimo SET® LNCS Adtx, adult sensor). Measurements were performed in the supine position on a trauma stretcher. A reusable probe was held on the right or left index finger for about 3 min. After the pulse wave was verified to be artifact-free and a constant value was obtained on the monitor, the PI value was obtained and recorded manually by emergency physicians, who were trained for PI measurement and unaware of the trauma severity.

A venous blood sample was obtained and put into ethylenediaminetetraacetic acid-containing tubes (up to the indicated line, about 2 mL) for complete blood count at the time of ED admission. Analyses were conducted via SYSMEX XN-1000 complete blood count device with the model year of 2007. For blood gas analysis, a venous blood sample was put into the heparin-containing injector. Lactate, pH, and BD values were analyzed via

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RADIOMETER ABL800 BASIC blood gas analyzer with the model year of 2011.

SI was calculated by dividing pulse rate by systolic blood pressure (millimeters of mercury) at the time of admission. RTS was derived according to the formula: RTS = (0.9368 × Glasgow Coma Scale score) + (0.7326 × Systolic Blood Pressure) + (0.2908 × Respiratory Rate).

Estimated class of hemorrhage was determined and recorded according to the classification in current trauma guidelines (4).

Statistical Analysis

Patients' demographic features were presented through descriptive statistical information such as number, percentage, and standard deviation. Shapiro-Wilk test was used to determine the normal distribution. Ordinal variables were presented as median values and interquartile ranges. Categorical variables were summarized as frequencies and percentages. The Mann-Whitney *U* and Kruskal-Wallis tests were used for determining the factors associated with PI. Spearman odds ratios (ORs) were presented with 95% confidence intervals (95% CI). Correlation analysis was used for comparison of continuous data with each other via MedCalc (version 19.1.3) software program. Binary logistic regression analysis was used to determine the risk factors. To compare the performance of PI, lactate, BD, SI, and RTS in predicting blood transfusion needs, receiver operating characteristic (ROC) curves were constructed and the area under the curve (AUC) was calculated via MedCalc (version 19.1.3) software program. Numerically obtained PI values were categorized as under 1 (abnormal) and above 1 (normal). Youden Index was used to determine the optimum sensitivity and specificity criterion value to determine the optimum cut point in ROC analysis. The AUC was found by ROC analysis (AUC = 0.921; $p < 0.001$). Youden Index value is 0.7569, where the specified associated criterion point is ≤ 1 sensitivity of 78.05; specificity value was found to be 97.64. Statistical analysis was performed using SPSS for Windows (IBM SPSS Statistics for Windows, Version 21.0, released 2012; IBM Corporation, Armonk, NY).

RESULTS

The study included 338 patients who came to the ED with multitrauma. Mean age was 40.8 ± 17.94 years (range: 18–95 years).The number of male patients was 235 (69.5%). Data on the trauma mechanism and the initial median of vital signs and laboratory parameters of the patients at the time of ED admission are shown in Table 1.

In 39 (11.5%) of 338 patients, peripheral PI was measured < 1. The median was 4.41 (Q1–Q3: 1.9–6.3). The relation between the categorical measurement of PI and the variables were examined. There was a positive correlation with hemoglobin ($p < 0.001$; r: 0.320), hematocrit ($p < 0.001$; r: 0.294), BD ($p < 0.001$; r: 0.315), pH ($p < 0.05$; r: 0.235), SBP ($p < 0.001$; r: 0.146), DBP ($p < 0.001$; r: 0.259), and SpO_2 ($p < 0.001$; r: 0.197). A negative correlation was detected with lactate ($p < 0.05$; r: −0.117), pulse ($p < 0.001$; r: −0.326), and respiratory rate ($p < 0.001$; r: −0.231).

PI had a negative correlation with SI ($p < 0.001$; r: −0.257) and a positive correlation with the RTS ($p < 0.001$; r: 0.344). No relation was found between PI and age ($p = 0.999$).

When stratified by the class of hemorrhagic shock, the patients were classified as follows: 261 (77.2%) patients as class I, 52 (15.3%) as class II, 20 (5.9%) as class III, and 5 (1.4%) as class IV. Table 2 shows the relationship between class of hemorrhagic shock and PI. According to the Comparison of Column Proportions, a significant difference was detected between classes 1 and 2, and between classes 1 and 3 (both $p < 0.05$). The comparison between the shock class and quantitative PI values revealed a significant difference between class 1 and 2 ($p < 0.001$), between class 1 and 3 ($p < 0.001$), and between class 1 and 4 ($p < 0.001$). No significant difference was found between class 2 and 4 ($p < 0.148$), between class 3 and 4

Table 1. Comparison of Trauma Type, Mechanism and *Median* Values of Vital Signs,Laboratory Values, Shock Index and Perfusion Index

	Male (n = 235)	Female (n = 103)
Trauma type		
Blunt (%)	217 (88.1)	103 (100)
Trauma mechanism		
Motor vehicle collision (%)	81 (34.5)	55 (53.4)
Pedestrians (%)	12 (5.1)	13 (12.6)
Fall from height (%)	59 (25.1)	26 (25.2)
Motorbike accident (%)	40 (17)	4 (3.9)
Beating (%)	9 (3.4)	5 (4.8)
Firearm injury (%)	6 (2.6)	–
Cutting and piercing injury (%)	22 (9.4)	–
Variables	Median	Q1–Q3
SBP (mm Hg)	120	110–130
DBP (mm Hg)	80	70–80
Heart rate (p/min)	88	80–98.25
Respiratory rate (p/min)	20	18–20
SpO_2 (%)	97	94–98
Hemoglobin (mg/dL)	14.3	13–156
Hematocrit (%)	41.6	37.8–45.3
Lactate (mmol/L)	2.2	1.5–3.02
Base excess (mmol/L)	−1.3	−3.7–0.2
pH	7.39	7.35–7.42
Shock index	0.72	063–0.87
Perfusion index	4.1	1.9–6.3

SBP = systolic blood pressure; DBP = diastolic blood pressure; SpO_2 = oxygen saturation.

Table 2. Comparison of PI With Class of Hemorrhagic Shock

	Class of Hemorrhagic Shock			
	Class I (n = 261)	Class II (n = 52)	Class III (n = 20)	Class IV (n = 5)
PI values, median (Q1–Q3)	4.6 (2.6–6.6)	2.15 (0.9–4.12)	0.9 (0.7–1.3)	0.6 (0.33–0.61)
PI > 1, n (%)	256 (98.1)	38 (73.1)	5 (25)	0
PI < 1, n (%)	5 (1.9)	14 (26.9)	15 (75)	5 (100)

PI = perfusion index.

($p < 0.397$), and between class 2 and 3 ($p < 0.101$). Blood transfusion, according to class of hemorrhagic shock, is shown in Table 3.

In the analysis performed by assuming a threshold value of 1, PI < 1 was found in 32 of 41 patients who received a blood transfusion (Table 4). Thirty-two of the patients with PI < 1 (82.1%) and 9 of the patients with PI > 1 (3%) had blood transfusion within 24 h ($p < 0.001$) (OR 147.302, 95% CI 51.390–422.22; sensitivity 78%, 95% CI 66–86.2; specificity 97.6, 95% CI 96–98.8; positive predictive value 82.1%, 95% CI 69.4–90.6; negative predictive value 97%, 95% CI 95.3–98.1). As a result of univariate analysis, major risk factors were determined by binary logistic regression analysis for blood transfusion need. Significant risk factors are listed in Table 5.

Finally, an ROC curve was constructed for the need for blood transfusion. Figure 1 shows that in predicting blood transfusion need in 24 h, PI was found as a more significant predictor than lactate level, BD, RTS, and SI measurements (respectively, AUC and p values were: 0.921, 0.0283; 0.737, 0.0432; 0.772, 0.0445; 0.855, 0.0453; and 0.729, 0.0399).

DISCUSSION

The main finding of this study is the outcome that low PI is a good indicator of blood transfusion need in patients with multitrauma. The results revealed that transcutaneous measurement of PI from the fingertip could indicate hypovolemia (i.e., shock, systolic blood pressure, pulse rate, SI, lactate, and BD. Furthermore, PI is also correlated with the RTS. With regards to patient management, it was demonstrated that abnormal PI measurements might be beneficial in the early prediction of blood transfusion needs in 24 h, after trauma in the ED. Our study is the first study performed with perfusion measurement to determine the severity of trauma and blood need due to hypovolemia in trauma.

PI is the ratio of the pulsatile blood flow to the nonpulsatile blood flow or static blood in peripheral tissue. PI, as an evaluation of pulsatile force in a specific monitoring site (e.g., hand, finger, or foot), is an indirect and noninvasive measure of peripheral perfusion. The one in the PI occurs as a result of the changes in the oxygenated blood flow volume in tissue circulation. PI measurement is independent from other physiological variables such as pulse rate variability, $SatO_2$%, oxygen consumption, or body temperature.

Traumatic injuries may vary from small isolated injuries to life-threatening complicated multiple injuries. The most common causes of trauma deaths are bleeding, multiple organ dysfunction syndromes, and cardiopulmonary arrest (15). Deaths usually occur at the scene or within 4 h of arrival to the health center. Deaths within 24 h of injury are relatively less common (16). Increased risk of death in the early hours of multitrauma is identified with the "golden hour" term, and the need for rapid intervention at this time of injury is also emphasized in the trauma guidelines (17). Thus, identifying critical patients and early detection of shock and impaired organ perfusion is essential to avoid tissue hypoxia (i.e., mortality and morbidity).

In trauma patients, as seen in airway problems, hemorrhage is also one of the preventable causes of morbidity and mortality if it is diagnosed and treated in the early stages (15). Hypotension is one of the most important indicators of hemorrhage. However, hypotension is a late marker of hypoperfusion and it might not usually be seen until the patient lost at least 30% of their blood volume (18). Hemorrhagic shock is a condition characterized by decreased tissue perfusion, cellular hypoxia, organ damage, and rapid, significant blood loss. Thus, early diagnosis of hemodynamic instability in trauma

Table 3. Distribution of Blood Necessities Among Shock Stages

Variables	Class I (n = 213)	Class II (n = 52)	Class III (n = 20)	Cass IV (n = 5)
Blood in 24 h, n (%) (n = 41)	3 (1.1)	17 (32.7)	16 (80)	5 (100)

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Table 4. Perfusion Index and Blood Transfusion in 24 Hours Comparison

	PI < 1 n = 39 (%)	PI > 1 n = 299 (%)	*p* Value	OR (95% CI)	Sensitivity (%)	Specificity (%)	PPV (%)	LR+	NPV (%)	LR−
Blood transfusion in 24 h (n = 41)	32 (82.1)	9 (3)	< 0.001	147.3 (51.3–422.2)	78	97.6	82.1	33	97	0.22

PI = perfusion index; OR = odds ratio; CI = confidence interval; PPV = positive predictive value; LR = likelihood ratio; NPV = negative predictive value.

patients is essential to prevent organ dysfunction. As PI is based on the photoelectric plethysmographic signal of a pulse oximeter, it might show real-time changes in peripheral blood flow. Therefore, PI might be an early indicator of shock in the context of a response to acute changes in blood volume. There are studies that demonstrate the relationship of peripheral finger perfusion (derived with different methods) with pulse rate, blood pressure, and cardiac flow in the previous literature (19,20). In their studies, Lima and colleagues stated that peripheral vasoconstriction was frequent in critically ill patients and this condition was associated with blood lactate and organ failure (21). Hasanin et al. demonstrated that PI can decrease with hypotension in shocked patients, whereas it would increase with hypotension in patients under anesthesia (22). Thus, it is more precisely correlated with the sympathetic tone (22). Another study revealed a linear correlation of PI with pulse rate in newborns under stress-free conditions, and this condition was identified with increased pulse rate originating from increased oxygen demand (23). De Felice et al. showed that low PI value is a clear and certain indicator in predicting severity of illness, and Rasmy et al. demonstrated that PI was already used for evaluation of the severity of septic patients and could predict the need of vasopressors and mortality in septic patients (24,25).

In their study on hypovolemic patients, Van Genderen and colleagues showed that PI decreased much earlier than the beginning of cardiovascular instability (26). So, even though blood pressure remains at the normal levels, PI might predict hypovolemia at the preshock stage (26). In our study, we also saw that PI may help us predict shock in the early stages as it can be measured easily and fast at the bedside of the patient. Thus, more comprehensive studies might be conducted on the use of PI in multitrauma patients in the ED as a predictor of fluid resuscitation and need for blood products. Even though PI cannot indicate hypovolemia alone, it might reveal changes in peripheral perfusion. Also, in multitrauma patients, shock is due to bleeding unless the perfusion disorder has been proven to be due to another cause. However, low perfusion can occur with hypovolemia secondary to trauma or hypothermia secondary to pain. Van Genderen and colleagues stated that initial measurement was more valuable than continuous measurements (26). They further characterize PI, as a decrease at the

Table 5. Univariate Analysis for Determining Major Risk Factors for Blood Transfusion Need by Binary Logistic Regression Analysis

						95% CI for OR	
	β	Std. Error	Test Statistics	*p* Value	OR	Lower	Upper
First Step							
SBP (mm Hg)	−.017	.020	.669	.413	.984	.945	1.023
DBP (mm Hg)	−.011	.038	.091	.763	.989	.918	1.065
Pulse rate (p. min)	.043	.017	6.464	.011	1.044	1.010	1.079
Respiratory rate (p. min)	−.022	.088	.062	.803	.978	.823	1.162
spO_2 (%)	−.166	.067	6.217	.013	.847	.743	.965
Hb (mg/dL)	−.063	.458	.019	.891	.939	.383	2.306
Htc (%)	−.012	.171	.005	.945	.988	.706	1.383
pH	−.723	4.647	.024	.876	.485	.000	4376.415
Lactate level (mmol/L)	.028	.164	.030	.863	1.029	.746	1.418
Base deficit (mEq/L)	−.082	.086	.925	.336	.921	.778	1.089
Perfusion index	−.562	.193	8.486	.004	.570	.390	.832
Constant	21.119	34.997	.364	.546	1485224359.490		
Last step							
Pulse rate (p. min)	.060	.015	16.755	.000	1.062	1.032	1.092
spO_2 (%)	−.207	.058	12.948	.000	.813	.726	.910
Perfusion index	−.685	.189	13.158	.000	.504	.348	.730
Constant	13.367	5715	5.471	.019	638578.380		

OR = odds ratio; CI = confidence interval; SBP = systolic blood pressure; DBP = diastolic blood pressure; HB = hemoglobin; Htc = hematocrit.

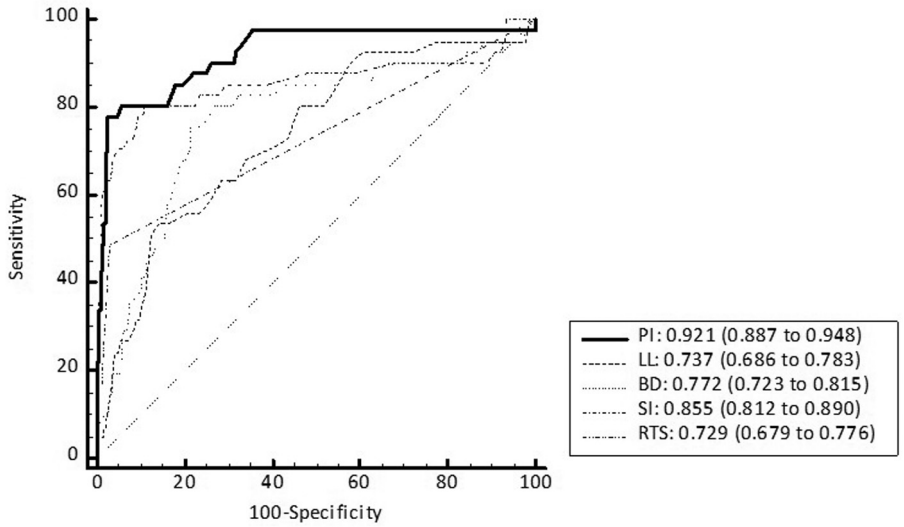

Figure 1. Comparison of ROC curve for predicting blood transfusion need in 24 hours with PI, LL, BD, SI and RTS. PI = perfusion index; LL = lactate level; BD = base deficit; SI = shock index; RTS = revised trauma score.

beginning of hypovolemia, followed by a fast increase in PI along with collapse. The study also stated that this condition caused a reduction in stroke volume and cardiovascular collapse, as it induced loss of sympathetic tone and concurrent decrease in peripheral tone secondary to a decrease in pulse rate (26).

In this investigation, PI measurements were performed in the resuscitation room where trauma patients got their initial evaluation in the ED. A strong relationship was detected between PI and fluid loss in multitrauma patients at the early stages. This study demonstrates that PI measurement might be a parameter useful for determining the need for blood transfusion due to its statistically strong correlation with the indicators of blood loss: SBP/DBP, pulse rate, hemoglobin, hematocrit, lactate, BD, and SI. Furthermore, according to ROC analysis, PI was superior to lactate, BD, RTS, and SI. Based on the data derived here, it can be argued that PI, along with its high sensitivity and specificity values, can be used as an essential indicator in identifying or excluding the need for blood transfusion in trauma patients at the early stages.

Recent studies on trauma found that an increase in lactate concentrations and the worsening BD was related to mortality. However, although abnormal values in both parameters increase doubts about a severe injury, it is also argued that normal values do not exclude severe injury. In trauma patients, PI measurement can be beneficial in the management of trauma patients when it is evaluated along with other physiological parameters and values such as lactate and BD. As Lima and colleagues suggested, in critically ill patients, impaired peripheral circulation can be reflected with changes in PI (21). However, this study is the first one to relate measurement to traumatic patients.

These results might be the first to demonstrate the relation of PI with reduced blood volume in trauma patients.

Limitations

PI is affected by conditions such as pain, emotional stress, or hypothermia. Patients included in this study may have experienced hypothermia or hyperthermia, as well as the pain and emotional stress often seen in trauma patients. Such conditions should be considered in the evaluation of PI.

Saline infusions were performed in all patients prior to their arrival to the hospital, however, the amounts of the infusions were not found in the records of the prehospital setting.

One other important limitation of the study was that there was no information about the change that occurs between the first assessment of the patient and the second assessment on arrival to the hospital.

CONCLUSION

PI values are correlated with all clinical and laboratory parameters derived in the ED and used for shock classification under emergency conditions. PI measurement might be a beneficial parameter in the detection and exclusion of critical patients in emergency situations.

PI derived from pulse oximeter can be used with vital signs and shock parameters in the early diagnosis of conditions that might trigger changes in peripheral circulation secondary to hemodynamic instability in trauma patients. Likewise, in a stable patient, a sudden drop in PI might indicate possible circulatory disorders. Furthermore, it might also be a beneficial criterion in the

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identification of critically ill patients, as well as assist with triage and transportation of these patients to appropriate trauma centers.

REFERENCES

1. Rossaint R, Bouillon B, Cerny V, et al. Management of bleeding following major trauma: an updated European guideline. Crit Care 2010;14:R52.
2. Kauvar DS, Wade CE. The epidemiology and modern management of traumatic hemorrhage: US and international perspectives. Crit Care 2005;9(suppl 5):S1–9.
3. Adrogue HJ, Madias NE. Management of life-threatening acid-base disorders. First of two parts. N Engl J Med 1998;338:26–34.
4. Galvagno SM Jr, Nahmias JT, Young DA. Advanced Trauma Life Support® Update 2019: management and applications for adults and special populations. Anesthesiol Clin 2019;37:13–32.
5. Mutschler M, Nienaber U, Münzberg M, et al. The Shock Index revisited - a fast guide to transfusion requirement? A retrospective analysis on 21,853 patients derived from the TraumaRegister DGU. Crit Care 2013;17:R172.
6. Manoochehry S, Vafabin M, Bitaraf S, Amiri A. A comparison between the ability of revised trauma score and Kampala Trauma Score in predicting mortality: a meta-analysis. Arch Acad Emerg Med 2019;7:e6.
7. Siegel JH, Rivkind AI, Dalal S, Goodarzi S. Early physiologic predictors of injury severity and death in blunt multiple trauma. Arch Surg 1990;125:498–508.
8. Levi Y, Jeroukhimov I, Peleg K, Rozenfeld M, Shavit I, Kozer E. Base excess as a predictor for injury severity in pediatric trauma patients. J Emerg Med 2013;45:496–501.
9. Abdul-Malak O, Vodovotz Y, Zaaqoq A, et al. Elevated admission base deficit is associated with a complex dynamic network of systemic inflammation which drives clinical trajectories in blunt trauma patients. Mediators Inflamm 2016;2016:7950374.
10. Strnad M, Lesjak VB, Vujanović V, Pelcl T, Križmarić M. Predictors of mortality and prehospital monitoring limitations in blunt trauma patients. Biomed Res Int 2015;2015:983409.
11. Mofidi M, Hasani A, Kianmehr N. Determining the accuracy of base deficit in diagnosis of intra-abdominal injury in patients with blunt abdominal trauma. Am J Emerg Med 2010;28:933–6.
12. Vandromme MJ, Griffin RL, Weinberg JA, Rue LW 3rd, Kerby JD. Lactate is a better predictor than systolic blood pressure for determining blood requirement and mortality: could prehospital measures improve trauma triage? J Am Coll Surg 2010;210:861–7.
13. Cheddie S, Muckart DJJ, Hardcastle TC. Base deficit as an early marker of coagulopathy in trauma. S Afr J Surg 2013; 51:88–90.
14. Goldman JM, Petterson MT, Kopotic RJ, Barker SJ. Masimo signal extraction pulse oximetry. J Clin Monit Comput 2000;16:475–83.
15. Teixeira PG, Inaba K, Hadjizacharia P, et al. Preventable or potentially preventable mortality at a mature trauma center. J Trauma 2007;63:1338–46.
16. Demetriades D, Kimbrell B, Salim A, et al. Trauma deaths in a mature urban trauma system: is "trimodal" distribution a valid concept? J Am Coll Surg 2005;201:343–8.
17. ATLS Subcommittee; American College of Surgeons' Committee on Trauma; International ATLS working group. Advanced trauma life support (ATLS®): the ninth edition. J Trauma Acute Care Surg 2013;74:1363–6.
18. Kirkpatrick AW, Ball CG, D'Amours SK, Zygun D. Acute resuscitation of the unstable adult trauma patient: bedside diagnosis and therapy. Can J Surg 2008;51:57–69.
19. Schriger DL, Baraff LJ. Capillary refill–is it a useful predictor of hypovolemic states? Ann Emerg Med 1991;20:601–5.
20. Bailey JM, Levy JH, Kopel MA, Tobia V, Grabenkort WR. Relationship between clinical evaluation of peripheral perfusion and global hemodynamics in adults after cardiac surgery. Crit Care Med 1990;18:1353–6.
21. Lima AP, Beelen P, Bakker J. Use of a peripheral perfusion index derived from the pulse oximetry signal as a noninvasive indicator of perfusion. Crit Care Med 2002;30:1210–3.
22. Hasanin A, Mohamed SAR, El-Adawy A. Evaluation of perfusion index as a tool for pain assessment in critically ill patients. J Clin Monit Comput 2017;31:961–5.
23. Sahni R, Schulze KF, Ohira-Kist K, Kashyap S, Myers MM, Fifer WP. Interactions among peripheral perfusion, cardiac activity, oxygen saturation, thermal profile and body position in growing low birth weight infants. Acta Paediatr 2010;99:135–9.
24. De Felice C, Latini G, Vacca P, Kopotic RJ. The pulse oximeter perfusion index as a predictor for high illness severity in neonates. Eur J Pediatr 2002;161:561–2.
25. Rasmy I, Mohamed H, Nabil N, et al. Evaluation of perfusion index as a predictor of vasopressor requirement in patients with severe sepsis. Shock 2015;44:554–9.
26. van Genderen ME, Bartels SA, Lima A, et al. Peripheral perfusion index as an early predictor for central hypovolemia in awake healthy volunteers. Anesth Analg 2013;116:351–6.

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ARTICLE SUMMARY

1. Why is this topic important?

Trauma is one of the most frequent emergency department admissions. Determining the severity or shock of the trauma is important for the prevention of mortality and morbidity. Measurement of perfusion index (PI) may help emergency medical practitioners to determine severity. Research on this subject is limited in the literature. We believe that this study can help emergency physicians predict hypovolemia due to blood loss in trauma patients.

2. What does this study attempt to show?

This study shows us that PI measurement can be used together with lactate, base deficitis, and shock index for determining the severity of trauma patients.

3. What are the key findings?

PI measurement can be used to determine the severity of hypovolemia.

4. How is patient care impacted?

PI measurement may be useful in detecting or excluding patients who will need blood transfusion due to hypovolemia in the early period.